Theoferometer for the Construction of Precision Optomechanical Assemblies

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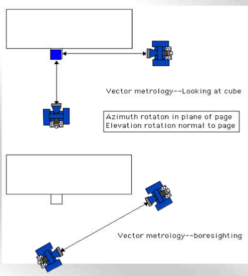
Vector Metrology and the Theodolite



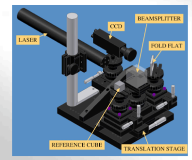
- Vector metrology is the measurement system used to determine the orientation and envelope of critical components on space flight hardware.
- The current accepted tool for vector metrology, a theodolite, is a telescope mounted such that it can be rotated in both a vertical and horizontal circle, yielding the pointing direction in azimuth and elevation.
- Theodolites and mirrored alignment cubes are used to acquire measurements for constructing a spacecraft coordinate system, with an uncertainty of ± 2 arcseconds since the human eye is used to align reticules off the reference and test surfaces.

Theodolite

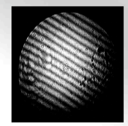
Project Overview

- Future projects, including FKSI and SPECS, have metrology requirements as low as 0.1 arcseconds, a standard unachievable with a theodolite.
- The theoferometer is capable of providing the required accuracy by removing much of the human error associated with the operation of a theodolite, making it a realistic choice to become the primary vector metrology tool in the 21st century.
- Characteristic testing demonstrated a measurement uncertainty of 0.3 arcseconds for the prototype theoferometer.
- Theoferometer concept well received in a paper given at the 2006 SPIE Astronomical Telescopes and Instrumentation Conference
- Concept success led to optical and mechanical redesign and software upgrades to increase instrument sensitivity and reduce measurement uncertainty to 0.1 arcseconds or better.
- My contribution to the project is:
  - Assembly of the second generation theoferometer
  - Alignment, testing, demonstration, and documentation

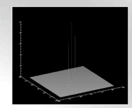
Theoferometer Layout and Use



Theoferometer Optics Schematic

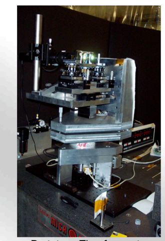


Interferogram

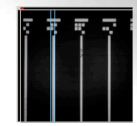


Fourier Transform

- The theoferometer is an interferometer mounted on a 2-axis rotation stage, allowing for 360° of rotation in azimuth and ~30° of rotation in elevation.
- Rotary NASA encoders read absolute position for each stage, with a resolution of 0.04 arcseconds.
- Piezoelectric inchworm motors adjust position by rotating each stage on a high quality bearing.
- Motors operate in open loop mode for manual control and in closed loop for automated fine alignment.
- Bitmap images of fringe patterns are processed using a Fourier transform algorithm in IDL, and azimuth and elevation tilts are displayed on the user interface.



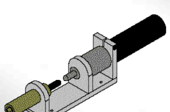
Prototype Theoferometer



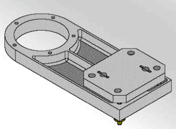
Encoder Image

Redesign Objectives

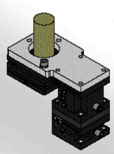
- Improve the uncertainty of measurements taken with the theoferometer from 0.3 arcseconds to 0.1 arcseconds or better by addressing problems with stability, vibration, and ease of alignment.
- Compact the overall design to make the theoferometer a portable instrument for metrology applications.
  - Eliminate reliance on compressed air supply by switching to mechanical bearings.
  - Switch to diode laser to reduce thermal drift caused by HeNe heat loads.
- Add a polarizer assembly to the optics to eliminate stray reflections and improve fringe contrast and clarity.
- Demonstrate measurement uncertainty levels at or below 0.1 arcseconds by repeating sensitivity, orthogonality, leveling, and cube calibration testing.



Inchworm Motor Assembly

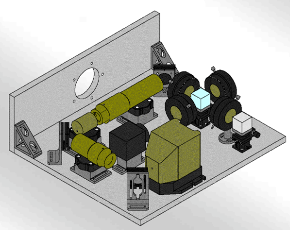


Midplate Leveling Assembly

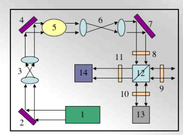


Encoder Readhead Mount

Optical and Mechanical Design

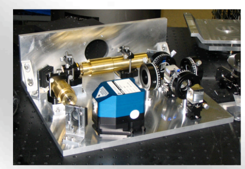


Optical Stage Assembly

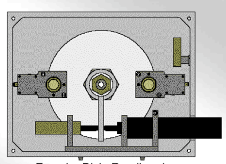


Redesigned Optical Layout

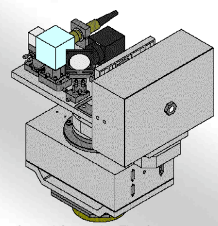
1: Laser, 2: fold flat, 3: expander/collimator, 4: fold flat, 5: anamorphic prism, 6: expander/collimator, 7: fold flat, 8,9,10,11: polarizer plates, 12: polarized beamsplitter, 13: reference cube, 14: CCD



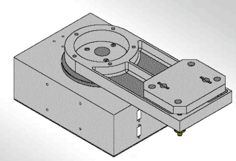
Optical Stage Hardware



Encoder Disk, Readheads, and Inchworm Motor Assembly



Second Generation Theoferometer



Rotary Stage and Midplate Assembly

Future Work on the Project

- Complete external hardware integration, assembly of existing hardware, and align the optical stage.
- Redesign the rotary stage and rotary shaft support.
- Check orthogonality of azimuth and elevation stages and level the azimuth stage.
- Repeat sensitivity testing and use the theoferometer to calibrate an alignment cube previously calibrated with a theodolite.
- Demonstrate use in lab / cleanroom environment on flight hardware with an uncertainty of 0.1 arcseconds or better.
- Deliver the theoferometer for off-the-shelf use as the replacement of the theodolite as the primary tool for vector metrology.

Acknowledgements

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